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THE FREEZING POINT OF POTATOES AS DETERMINED BY THE THERMOELECTRIC METHOD.[1]

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HISTORICAL SUMMARY.

Definite data on the exact freezing point of the potato (*Solanum tuberosum*) are not to be found in the literature, owing possibly to the wide variations in the methods and materials used by different investigators. Up to the present time practically all data on the freezing point of potato tubers have been obtained by the use of thermometers of the mercury or a similar type. So far as published data are concerned, Apelt[2] was apparently the first to use the thermoelectric method of determining the freezing points of potatoes.

Müller-Thurgau[3] was one of the first investigators to publish the results of investigations on the freezing point of potatoes. In 1880, in presenting his findings in connection with various plants, he gave the freezing point of potatoes as 30.21° F. (−1.8° C.). Appleman[4] in his study of the changes in potatoes during storage found that the tubers freeze when the temperature is between 28° and 26° F. (−2.2° and −3.3° C.). According to the results of Jones, Miller,

[1] This bulletin presents the results of a portion of the work carried on in the Bureau of Plant Industry under the project "Factors affecting the storage life of vegetables."

[2] Apelt, Arthur. "Neue Untersuchungen über den Kältetod der Kartoffel." Beitrage zur Biologie der Pflanzen Cohn. Bd. 9, p. 215–261. 1907.

[3] Müller, Hermann, *Thurgau.* Ueber das Gefrieren und Erfrieren der Pflanzen. *In* Landw. Jahrb. Bd. 9, p. 133–189, pl. 1–4. 1880.

[4] Appleman, C. O. Changes in Irish potatoes during storage. Md. Agr. Exp. Sta. Bul. 167, p. 327–334. 1912.

and Bailey[5] the freezing point is near 28.4° F. (−2.0° C.). Potatoes, since their sap is a solution of salts, sugar, and various soluble materials, freeze at a lower temperature than pure water. Müller-Thurgau found that the expressed sap froze at 30.8° F. (−0.65° C.), while the living potato tissue froze at a lower temperature. He also brought out the fact that undercooling usually takes place before freezing. According to his results a temperature ranging from 26.25° to 20.3° F. was necessary before freezing commenced; subsequently the temperature rose to the true freezing point. Müller-Thurgau further showed that the living tissue required more undercooling than the expressed sap. Jones, Miller, and Bailey[5] brought out further data on the subject of undercooling, which will be discussed later.

PLAN OF THIS INVESTIGATION.

For greater accuracy, the thermoelectric method was used to measure temperatures. Practically the same arrangement for temperature measurements was used as is described and figured by Harvey.[6] A 5-junction copper-constantan couple of the needle type described by Taylor[7] was used in all determinations, in connection with a Wolff type potentiometer and a Wolff suspension galvanometer. With this arrangement it was not possible to use entire potatoes. However, in order to determine whether the freezing points of such sections were comparable with those of whole potatoes, a different type of freezing apparatus was temporarily used, in which whole potatoes as well as sections could be frozen. It was shown that the results were identical. The advantage of using sections of potatoes as described is apparent, since these can be frozen much more quickly than whole specimens.

Standard sections from at least two places near the center of each potato were cut with a cork borer. These sections were about three-eighths of an inch in diameter by $1\frac{1}{4}$ inches in length. A hole was bored lengthwise nearly the full length of the section, into which the thermocouple was thrust. After all surface moisture was blotted off with a clean towel, the thermocouple with the section of potato was suspended through a stopper in the inner or freezing tube of the freezing apparatus. Ordinarily, the surrounding ether was kept between 17° and 16° F. Repeated trials showed no consistent difference in the freezing points of portions taken from different parts of the potato. It was found that considerable time could be saved in each determination if the potato was inoculated (see the explana-

[5] Jones, L. R., Miller, M., and Bailey, E. Frost necrosis of potato tubers. Wis. Agr. Exp. Sta. Research Bul. 46, 46 p., illus. 1919.

[6] Harvey, R. B. The importance of epidermal coverings. *In* Bot. Gaz., v. 67, no. 5, p. 441–444, 2 fig. 1919.

[7] Taylor, G. F. Some improvements on the needle-type thermocouple for low temperature work. Jour. Indus. and Engin. Chem., v. 12, no. 8, p. 797–799. 1920.

tion of this term on p. 6) by tapping it sharply against the side of the freezing tube after it was undercooled to about 25° F. The true freezing point could then be found almost immediately. The freezing point was the same as though the potato had been allowed to undercool until self-inoculation took place. The whole operation from the time the section of the potato was inclosed in the freezing tube until the final freezing point was determined seldom took 30 minutes.

FREEZING POINTS OF DIFFERENT VARIETIES AND GROUPS OF POTATOES.

Determinations of the freezing point were made at four periods (Feb. 12, Feb. 18, Mar. 5, and Apr. 1) on seven standard varieties of potatoes: Irish Cobbler, Triumph, Spaulding No. 4, Russet Rural, Rural New Yorker, Green Mountain, and American Giant. In addition, in the last period freezing-point determinations were made on 11 additional varieties: First Early, New Early Standard, Producer, Oregon White Rose, Early Prospect, Up-to-Date, Gold Coin, Ehnola, Garnet Chili, British Queen, and United States Seedling No. 38774. These potatoes were all true to name and were all grown under the same conditions at the Aroostook Farm of the Maine Agricultural Experiment Station under the direction of William Stuart, of the Office of Horticultural and Pomological Investigations. On arrival at Washington they were placed in storage at 40° F. Duplicate determinations were made from at least two specimens of each variety. Generally, more were used; in some cases as many as eight specimens. Table I presents the average results in Fahrenheit and centigrade of all the freezing-point determinations made. The relative position of each variety on the list at each successive date is also stated. Table II gives the freezing points of all 18 varieties determined on April 1. These are arranged in varietal groups.

TABLE I.—*Freezing points and relative positions of seven varieties of potatoes on four successive dates.*

Variety.	Feb. 12.			Feb. 18.			Mar. 5.			Apr. 1.		
	Relative position.	°F.	°C.	Relative position.	°F.	°C.	Relative position.	°F.	°C.	Relative position.	°F.	°C.
Irish Cobbler	1	29.35	−1.47	1	29.18	−1.57	1	29.66	−1.30	1	29.66	−1.30
Triumph	3	28.77	−1.79	4	28.48	−1.96	2	29.38	−1.46	4	29.04	−1.56
Spaulding No. 4	5	28.28	−2.07	3	28.55	−1.92	3	29.35	−1.47	3	29.33	−1.48
Russet Rural	6	28.16	−2.14	6	28.32	−2.05	4	29.16	−1.58	7	28.32	−2.05
Rural New Yorker	4	28.42	−1.99	5	28.39	−2.00	6	29.08	−1.63	5	28.70	−1.84
Green Mountain	7	28.13	−2.16	7	28.22	−2.10	7	28.86	−1.75	6	28.50	−1.95
American Giant	2	29.00	−1.67	2	28.73	−1.82	5	29.13	−1.60	2	29.64	−1.31

It is unfortunate that freezing points were not obtained from these lots of potatoes soon after harvest and then followed up periodically throughout the storage season. Subsequent work will be directed along this line. From the results here presented, a general tendency toward a rise in the freezing point as the season advances is evident. A fairly distinct varietal difference in freezing points is shown to be rather consistent. This is contrary to the statement of Jones, Miller, and Bailey.[8] The order in which the varieties freeze, beginning at the highest point, is (Feb. 12) Irish Cobbler, American Giant, Triumph, Rural New Yorker, Spaulding No. 4, Russet Rural, Green Mountain; (Feb. 18) Irish Cobbler, Giant, Rose, Triumph, Rural New Yorker, Russet Rural, Green Mountain; (Mar. 5) Irish Cobbler, Triumph, Spaulding No. 4, Russet Rural, American Giant, Rural New Yorker, Green Mountain; (Apr. 1) considering only the above-named seven varieties, first, Irish Cobbler, then Triumph, Spaulding No. 4, Russet Rural, American Giant, Rural New Yorker, and Green Mountain. It is seen that the varieties in general follow in nearly the same order, there being some shifting of position with some of the varieties having intermediate freezing points.

TABLE II.—*Freezing points of 18 varieties of potatoes, arranged according to family groups.*

Group and variety.	Freezing point.		Group average.	
	°F.	°C.	°F.	°C.
Triumph:				
Triumph	29.20	−1.56	29.04	−1.65
Early Prospect	28.80	−1.74		
Cobbler:				
Irish Cobbler	29.67	−1.30	29.21	−1.55
First Early	29.00	−1.67		
New Early Standard	28.97	−1.69		
Michigan:				
Ehnola	29.17	−1.57	29.17	−1.57
Rose:				
Spaulding No. 4	29.33	−1.48	29.33	−1.48
Green Mountain:				
Green Mountain	28.50	−1.95	28.56	−1.91
Gold Coin	28.63	−1.87		
Rural:				
Rural New Yorker	28.70	−1.84	28.59	−1.95
Russet Rural	28.32	−2.05		
United States Seedling No. 38774	28.77	−1.79		
Up-to-Date:				
Up-to-Date	29.10	−1.71	28.96	−1.74
Producer	28.76	−1.80		
Oregon White Rose	28.71	−1.83		
British Queen	29.27	−1.52		
Peachblow:				
Garnet Chili	28.16	−2.14	28.16	−2.14
Uncertain:				
American Giant [1]	29.64	−1.31	.....	.....

[1] It is somewhat uncertain in what group the American Giant belongs. Judging from its parentage, it possibly should belong with the second section of the Green Mountain group, but since its freezing point is so widely different from the rest of that group it is shown here by itself.

In Table II all the 18 varieties are divided into family groups, according to Stuart.[9] The results shown in Table II were obtained

[8] Jones, L. R., Miller, M., and Bailey, E. Op. cit.

[9] Stuart, William. Group classification and varietal descriptions of some American potatoes. U. S. Dept. Agr. Bul. 176, 56 p., 19 pl. 1915.

in the period beginning on April 1. Unfortunately, specimens of these varieties could not be obtained for this work earlier in the season, since some of them were being held for another purpose. The data presented here bring out the fact that the relations of the freezing points of the members of the varietal groups are fairly consistent; also that freezing points can possibly be used in helping to classify varieties. The average freezing points of the early and midseason groups represented here by the Triumph, Cobbler, Michigan, and Rose families are distinctly higher than those of the late variety groups represented by the Green Mountain, Rural, Up-to-Date, and Peachblow families. It is somewhat uncertain where to class the American Giant variety. Prof. Stuart, on being asked his opinion, expressed uncertainty, but stated that judging from its parentage it should possibly be classed with the Green Mountain group, section 2. However, if one were classifying potatoes according to freezing points alone, this might belong with the early varieties.

UNDERCOOLING.

It has already been brought out that generally undercooling is necessary before potatoes begin to freeze and that according to Müller-Thurgau the range of undercooling is from 26.25° to 20.10° F. (−3.2° to −6.6° C.). According to the writers' experience, the degree of undercooling reached before freezing begins depends for one thing upon the rate of undercooling. This is in accord with the results of Jones, Miller, and Bailey,[10] who say that "the supercooling range seems to depend upon the air temperature and the rate at which this temperature is dropped. Thus at −3.5° C. (25.7° F.) the supercooling point approaches the air temperature. If the air temperature is dropped slowly to −5° C. (23° F.) or below, it will approach −5° C., while if dropped rapidly to the same point it will be much higher, i. e., nearer −3° C." This also depends to some extent upon the variety. The most important factors limiting the extent of undercooling are accidental external disturbing influences, such as jarring, or the freezing of moisture that accidentally may be on the outside of the material, or even touching with a crystal of ice. Any of these factors in greater or less degree will instantly terminate the undercooling process at any point below the true freezing point. As undercooling advances, the stability of the liquid state of the sap within the tissue becomes more and more strained until a point is reached when the slightest perceptible jar will terminate the undercooling, and freezing will begin instantly. The temperature of the tissue then rises with extreme rapidity to the true freezing point. No attempt has been made to record accurately the time occupied while the temperature rises from the maximum degree of under-

[10] Jones, L. R., Miller, M., and Bailey, E. Op. cit.

cooling to the freezing point, but it is thought not to take more than fifty seconds. It was found usually that if not undercooled too rapidly the potato sections would undercool to from 23° to 17.6° F. before self-inoculation took place.

INOCULATION.

The term inoculation has been used in this bulletin to mean the act of terminating by some mechanical means the undercooling process

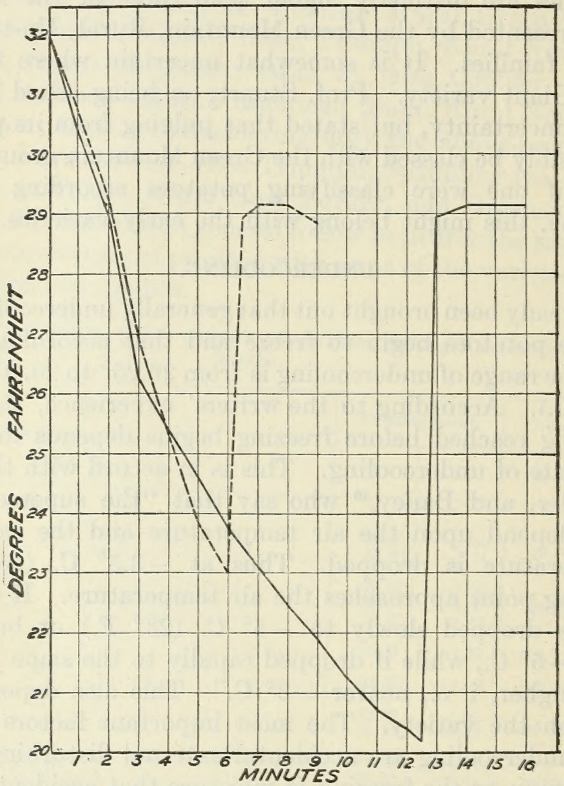

FIG. 1.—Diagram showing the undercooling and freezing points of two potatoes. One tuber (represented by the solid line) was subjected to an air temperature of 15.8° F. The other tuber (represented by the broken line) was subjected to an air temperature of 8.7° F.

shortly after the freezing point has been passed. It is considered that this term is rightly used, as it is directly comparable to the process in physical chemistry, known by the same term, in which crystallization is started in a concentrated solution by adding a crystal of the solute or when freezing is started by adding a crystal of ice to pure water that has been undercooled.

All materials are not so easily inoculated as sections of the potato. While determining the freezing point of cranberries it was found necessary to undercool them to a degree considerably lower than

in the case of potato sections before tapping would start them to freeze. When undercooled to the same degree at which a slight tap would inoculate a potato section, even stabbing with a piece of wire would not cause the berries to freeze, although the temperature was then below the subsequent freezing point.

In figure 1 two typical lines show the degrees of undercooling and the freezing points of two potatoes. Readings were taken every minute. The potatoes were allowed to undercool undisturbed until self-inoculation took place. In one case, represented by the solid line, the ether surrounding the freezing tube was held at 15.8° F. In the other case, represented by the broken line, the ether was held at 8.7° F. In the first case the potato reached a temperature of 20.2° F. in 12.5 minutes after 32° F. was passed. At this point freezing commenced, and in half a minute the temperature had increased to 28.95° F., while in another half minute the freezing point, 29.15 F., was reached. Here, the temperature remained stationary for two minutes. With the other, undercooling proceeded at practically the same rate for six minutes, when 23° F. was reached and freezing commenced. In half a minute the temperature was 28.5° F. and in another half minute it was 29.15° F., the freezing point. Here it held for only a minute, when it commenced to fall, owing to the extremely low temperature of the surrounding air.

SUMMARY.

A thermoelectric method was used to determine the freezing point of 18 standard varieties of potatoes grown under the same conditions. The following facts were determined:

(1) The freezing point tends to rise as the season advances.

(2) The freezing point seems to vary with the variety.

(3) The freezing points of varieties of the same family group are often comparable.

(4) Early and midseason varieties have a higher freezing point than late varieties.

(5) Undercooling is terminated at any point by an outside influence, such as tapping or jarring.

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